Systems Engineering Research Center

Systems Engineering Capstone Marketplace

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BACKGROUND

The goal of this project was to continue to investigate methods and means to further the SERC Capstone Marketplace that was established in 2013 and refined in 2014. Previous SERC research in RT-19/19a, RT-43, & RT 105 has shown that multidisciplinary capstone programs can enhance development of systems engineering competencies.

The Capstone Marketplace is an online tool intended to match multi-disciplinary student teams with challenging engineering projects. While web based tools exist for matching students to projects at individual institutions, the Capstone Marketplace is intended to enable broader participation and as such is open to all institutions with the capability of participating in undergraduate level capstone projects. The marketplace project sponsors and/or mentors provide domain expertise and advice, students research the project details and work towards solutions, while faculty supervisors help guide the teams and grade their work. The Capstone Marketplace makes it easier for sponsors to reach out to a broad pool of students and provide them with the added benefit of an engaged and knowledgeable mentor. Students can more easily find projects best matched to their interests and needs and faculty have an open source for student projects that can lead to new research partners and collaboration.

The project consisted of four phases:
1. Initiating and supporting a third year of capstone marketplace projects
2. Marketing the Capstone Marketplace to attract additional sponsors and participating schools
3. Refining the Capstone Marketplace website/portal
4. Development of support materials for sponsors and schools that use the marketplace

Activities of these phases overlapped, but initiation and support of the third year and marketing for future projects were mostly separate.

PARTICIPATING SPONSORS AND PROJECTS

Project ideas and potential sponsors for the 2014-15 academic year student projects were sought through a combination of search strategies: sponsors and mentors of previous capstone projects, candidate leads suggested by SERC researchers, national laboratory contacts suggested by members of the OASD(R&E) STEM Development Office, and personal networking.

14 separate projects were proposed by 2 sponsors:

Sponsor	Project
**SOCOM	Advanced Body Armor
*SOCOM	Advanced Power Technologies
*SOCOM	Austere Landing Zone Assessment
*SOCOM	Avoiding Information Overload
**SOCOM	Vessel Disablement
*SOCOM	Enhanced Performance
*SOCOM	Water/Pressure-Activated Personal Flotation Device
*SOCOM	Armored Window Improvement
SOCOM	Body Worn Processor
SOCOM	Novel/Innovative Communications
SOCOM	Communications Junction Box Size Reduction
SOCOM	Stinger Box Improvement
US DoD	Cyber Wireless I&W: Behavioral Models
US DoD	Cyber Wireless I&W: Cognitive Radio Air Interface Experiment

The projects annotated with leading asterisks were matched to student teams. Multiple asterisks indicate multiple teams working independently on projects to solve similar sponsor requirements/needs.

PARTICIPATING SCHOOLS

We invited participation by engineering schools throughout the United States in this third year of the marketplace.

4 schools participated on 10 distinct projects:

School	Students
Georgia Tech University	1 team of 5 undergraduate electrical engineering, mechanical engineering, & computer science students
North Carolina A&T State University	3 undergraduate students in Industrial and Systems Engineering (11/14-5/15) followed by 4 undergraduate students in Industrial and Systems Engineering (8/15-12/15)
Stevens Institute of Technology	27 undergraduates students from; civil engineering, mechanical engineering, bio-medical engineering, electrical & computer engineering, & naval engineering across 6 distinct projects
University of Alabama in Huntsville (UAH)	12 undergraduate students in Mechanical & Aerospace Engineering (fall 2015-spring 2016) on 2 distinct projects followed by 9 undergraduate students in Mechanical & Aerospace Engineering (summer 2016-fall 2016) finalizing one project

In addition to the student teams that were matched with projects there were 2 student teams that submitted proposals/applications that were not matched. One team from Johns Hopkins University was unable to delay the start of their project until the sponsor's decision on which teams to support was provided. A second team proposed from Northern Illinois University was not selected by the sponsor.

PROJECT RESULTS

90% of the funded projects were deemed to be successful by the sponsors. Two of these projects were selected to be supported for a second year. One of these projects, the development of an inflatable personal flotation device (PFD) that could be programmed to inflate at a given depth-time combination was the first successful demonstration of such a device that the sponsor SME's had witnessed. They further stated that the sponsor had spent considerably more resources on industry development with less success.

There was a single project failure. There were several conditions associated with this project that may have contributed to this failure, the two most likely contributing factors were:

- An inability to establish proper initial communications between the sponsor SME and the team.
- The team was outside of the academic programs typical capstone design format leading to insufficient oversight.

The first point is a recurring problem and is addressed in a later section of this report. The second is not. There have been unconventional teams in previous CM projects that operated outside of the typical capstone design format and managed great success. One from the 2013-14 academic year had sufficient success that the sponsor initiated two projects to further investigate concepts developed in that project. The fault likely lies with the lack of oversight independent of the team's academic status. Future non-traditional projects should be closely monitored at the early stages to ensure that clear and agreed upon milestones are established between the team, the sponsor, and a dedicated faculty advisor.

A post project faculty survey indicated that from an academic perspective participation led to positive outcomes for the faculty and students. All faculty respondents indicated that they would participate in future CM projects and encourage their colleagues to investigate participation.

A key goal of the survey was to provide some assessment of the students SE learning over the course of the project by asking for responses to the following questions:

4. Provide a general assessment of the student team's abilities to successfully implement systems engineering concepts or activities at the beginning of the project. (1 2 3 4 5)
5. Provide a general assessment of the student team's abilities to successfully implement systems engineering concepts or activities at the end of the project. (1 2 3 4 5)
    a. To what degree did the students experiential learning from the project impact the improvement in their ability to implement systems engineering concepts or activities? (1 2 3 4 5)

The average response score for question four was a 3.3 indicating that most students had some experience and/or SE knowledge at the project outset. As more engineering programs work to incorporate some engineering management processes into the undergraduate curriculum this basic understanding or knowledge of some SE concepts is becoming more typical.

The average response score for question five was a 4.4 indicating a general increase in SE knowledge. Question 5a was intended to elicit more specific information connecting this new learning to the experiential nature of CM projects. The average response score to this question was a 4.3 indicating that participation in the CM project led to significant new SE learning. Several respondents included comments in this regard:

"Greatly as they appreciated the relevance and importance of the project and having the tangible end-result in mind (i.e. the final product) motivated them. My Armored Window Team was particularly motivated by the fact that SOCOM provided an Armored Toyota Land Cruiser in order to integrate their design. "

"The experience of working on this project increased the student's understanding of how to work on an engineering team towards the solution of a complex problem. They were forced to work and research outside of the technology or expertise typically associated with their majors"

WEBSITE

The core of Capstone Marketplace is the website which establishes the "market" where students, faculty, and mentors can view the potential projects. Figure 1 below is a timeline of the process of identifying, posting and matching projects to successful applicants. The website was populated with 10 of 12 projects for the 2014-15 academic year by end of the spring 2014 semester. A more appropriate time frame is mid-spring semester when students begin to pre-select projects and develop relationships that lead to team formation. The nature of the

academic calendar and its deviation from the primary projects sponsor's standards present a distinct challenge in this regard. Two additional projects were added to the website in the early August which is very late with respect to the selection of projects by students. Multiple attempts were made to engage schools to submit proposals for these late projects without success.
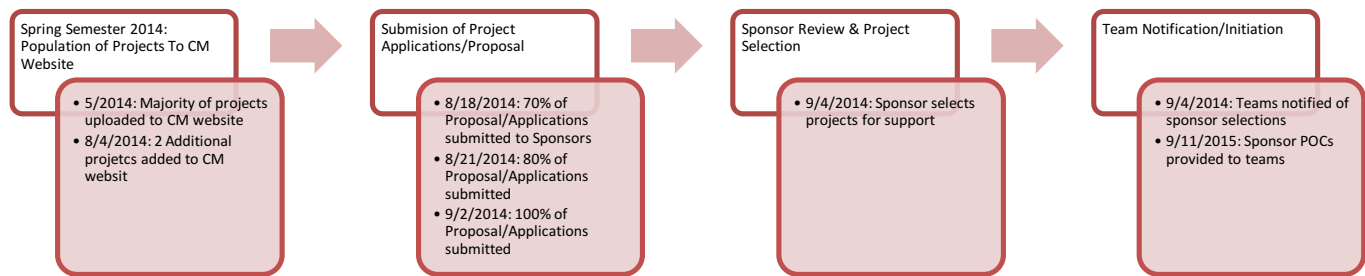
Spring Semester 2014: Population of Projects To CM Website	Submision of Project Applications/Proposal	Sponsor Review & Project Selection	Team Notification/Initiation
• 5/2014: Majority of projects uploaded to CM website • 8/4/2014: 2 Additional projetcs added to CM websit	• 8/18/2014: 70% of Proposal/Applications submitted to Sponsors • 8/21/2014: 80% of Proposal/Applications submitted • 9/2/2014: 100% of Proposal/Applications submitted	• 9/4/2014: Sponsor selects projects for support	• 9/4/2014: Teams notified of sponsor selections • 9/11/2015: Sponsor POCs provided to teams

Figure 1: Timeline of Project Matching Process

Information and resources were added to the website to better enable participating students and faculty to implement SE processes and tools and to provide guidelines for topics such as intellectual property, disclosure of project information, publication of research results, and communication protocols. The guidelines were intended to reduce some of the complications associated with the collaboration between undergraduate academic programs and US DoD sponsors with respect to procedures and processes that arose in previous Capstone Marketplace projects. In 2013-14 several issues regarding disclosure of information and communication breakdowns occurred. In 2014-15 only communication breakdowns between sponsors/mentors and teams occurred. These were successfully resolved with input from the Capstone Marketplace research team and the sponsor technical lead. In some instances these led to significant delays in teams getting initial information necessary for a successful project start. Delays in reporting these difficulties to the Capstone Marketplace research team magnified these issues. The implementation of a shared project calendar on the CM website may provide an opportunity for CM administrators to identify these breakdowns earlier and reduce negative impacts.

A new website was developed as part of this research with a several key goals; enabling the scaling of participation without creating excess administrative needs, enabling the transition of the marketplace from within the SERC to another independent entity or as a stand-alone service, and to improve the user experience and better establish the website as a project resource.

The list below identifies the new capabilities which will be implemented from the foundation previously set:
- Team formation:
    - Searchable key topics database that will tie together:
        - Project requirements as defined by the sponsor,
        - Areas of expertise or interest as defined by mentors and faculty,
        - Areas of interest, experience and academic disciplines as defined by the students.
        - This will enable identification of synergies between all users with the goal of better enabling multiple institution collaboration and participation of non-sponsor mentors or SMEs.
    - A message board to allow for communication at the preliminary team forming stages where potential students can establish a line of communication the same way students in a single institution may communicate amongst themselves to team form based on interest and capabilities.

- Project support:
  - The resources section of the website will continue to be expanded
    - A tool for securely storing relevant project materials will be added to enable sharing across institutions, sponsors, mentors, and if applicable the public viewers of the website.
    - A shared project calendar permitting transition to popular web based calendar tools.
- Assessment:
  - Core systems engineering principles are being established and a pre-project and post project assessment will be developed to better enable an assessment of student learning and the efficacy of the Capstone Marketplace.

OUTREACH FOR THE NEW SPONSORS AND ACADEMIC PARTICIPANT IN THE MARKETPLACE

SOLICITING PROJECT PROPOSALS FROM SPONSORS

Outreach to potential sponsors to provide information related to and solicit project support for the Capstone Marketplace took many forms from presentation and in-depth discussions of information at system engineering industry events, distribution of information and attendance at defense industry events, and discussions/networking with contacts developed through event participation; existing professional relationships, and information provided by existing sponsors.

Below is a summary of some of the key events attended and groups contacted and/or briefed on the Capstone Marketplace:

- NDIA 2015 SOLIC (Special Operations and Low Intensity Conflict)
  - Literature drop of CM industry focused document to all exhibitors
- NDIA 2015 SOFIC (Special Operations Forces Industry Conference),
  - CM discussed & industry focused CM information distributed at USSOCOM/SOF AT&L ST round table discussions
  - CM Project posters and looped video presented at special TALOS location
- INCOSE Corporate Advisory Board
  - Briefing
- NOAA/NWS
  - Briefing and discussions
- NAVFAC
  - Briefing and discussions
- Office of the Assistant Secretary of the Army (Acquisition, Logistics and Technology) (ASA(ALT)) System of Systems Engineering & Integration (SoSE&I) Directorate
  - Briefing and discussions
- SPAWAR
- DHS S&T
- Office of the Science, Technology, Engineering, & Mathematics (STEM) Development Program within Department of Defense

SOLICITING AND ENCOURAGING ACADEMIC PARTICIPATION

Outreach to potential academic participants to discuss and encourage participation in the Capstone Marketplace was conducted in a similar manner to the industry & government outreach. Additional efforts included the publication of a research paper in the proceedings of and attendance and presentation at 2015 American Society for Engineering Education (ASEE) Annual Conference and Exposition.

Below is a summary of some of the key events attended and groups contacted and/or briefed on the Capstone Marketplace:
- Capstone Design Community Gathering at ASEE 2015
- Conference on Systems Engineering Research (CSER 2015)
    - Briefing
- SERC collaborator WebEx
    - Briefing & Discussion
- 2015 Annual SERC Research Review (ASRR)
    - Briefing & Discussion

Additional outreach to individual institutions and faculty members was ongoing throughout the project. Several specific lessons learned from these discussions are:
- Many large to mid-size academic institutions have existing and long-standing relationships for capstone design sponsorship.
    - Many of these come with funding far in excess of current CM project funding
    - These funds are provided as a grant and not a subcontract
    - Many of these relationships are developed based on academic/industry connections at the individual level that are longstanding:
        - Alumni in industry
        - Retired industry professionals in academic positions
        - Previous research collaborations
- There is a significant perception that participation in the CM will require excessive administrative effort and reporting.
    - These are largely misperceptions as there is no additional academic reporting required, however in some instances the administrative effort on DoD projects (100% on this effort) has been challenging and has led to delays at the student level.
- It is imperative that the CM project sponsor schedule with respect to developing potential projects be aligned with the middle of the spring semester of the academic year preceding the project academic year (i.e. Projects to be pursued in the 2016-17 year be available on the CM in the spring (April 2016).
- Small schools are a potential source of participants as there ability to compete with larger institutions for industry or DoD support is limited.
- Student word of mouth (social media) should be actively pursued.

At Stevens we gave presentations to faculty supervisors of capstone projects and kept them aware of the status of new project proposals as they arrived. There is support for participation at Stevens, but proposals need to be available very early for their process. Most project teams are formed in the spring term, often in April. Delays in establishing which projects will be available for the following academic year continues to negatively impact participation.

4 schools submitted proposals/applications through the CM website including one new school and one school from a previous year that had opted to not participate due to timing and administrative logistics applied through

the CM website for 2015-16 academic year projects. One survey responded indicated attempts to broaden CM participation at their institution.

DEVELOPMENT OF SUPPORT MATERIALS

Dr. Armand J. Chaput at University of Texas at Austin developed a report titled SE Design Education for All Engineers available to post on the Capstone Marketplace as a capstone course instructor guide to teaching SE as a hands on principle of design based on the aerospace-based approach.

We investigated the integration of the SERC Experience Accelerator (EA) with the CM. This concept would implement an EA Lite as a standard requirement for all students participating in a CM project. This would enable the enhancement of the students basic understanding of SE processes and tools and allow for a pre-project skills assessment. A post project EA Lite requirement would enable the reinforcing of learned SE skills and knowledge and assessment information that could be used to quantify learning outcomes.

LESSONS LEARNED AND RECOMMENDATIONS

ROLE OF CLIENT AND MENTORS

The role of the sponsor's subject matter expert (SME) or mentor is critical to the success of the CM projects. It is critical that the sponsor clearly understands the role that these individuals of groups play in the CM process. This is especially true in the initial stages of the project when there is very short time-line that students must work within and they are in need of critical information from the mentor. Several projects from 2015-16 struggled to establish and maintain successful working relationships with their sponsor SME/mentors. When the problem was identified early corrective steps such as assigning additional mentors resolved the issue. When the problems were reported late or lingered the students and the project outcomes suffered. While each team was contacted at the outset of their project to assess progress additional outreach or reporting milestones through the new website would be a positive step in resolving these issues

Additional reviewers and mentors can sometimes be found by contacting local chapters of professional societies. Members of those chapters may be interested in the student projects and can help by mentoring or reviewing student work. Local chapters of ASME earn credit toward additional funding from their national organization by participating in these types of activities.

ROLE OF FACULTY

The CM does not replace the role of the faculty in the capstone design process. It is intended to be a means to connect students with sponsors & mentors. However, an unsuccessful effort on the part of the student team is detrimental to the CM's ability to solicit and maintain sponsors and mentors. While burdening students and faculty with additional reporting requirements is not a workable solution to this problem simple milestone reporting on a shared CM calendar that can be observed by CM administrators with automated simplified survey questionnaire e-mails at critical agreed upon milestone would be helpful to keep projects on track. These should be established by the team (faculty, sponsor, & students).

ROLE OF STUDENT

The most critical participants in the CM process are the students. The synergy of excited and motivated students engaged in a CM project and social media has the potential to broaden the pool of student participants. While it will be critical to manage a relative balance between applicants and projects this potential should be investigated. The new website was conceptualized to be not only a marketplace but additionally a virtual collaborative space and toolbox for the projects that could make it a frequent resource and a topic of student discussion. Encouraging and enabling these discussions is encouraged.

CONCLUSION

The CM continues to be viewed as a success by the participants across all three groups, academic, sponsor, and mentors. The limited number of participants presents a continuing problem for the long term viability of the CM. While efforts were made to broaden the pool of industry and government sponsors these efforts have thus far been unsuccessful. A primary hindrance to broaden participation is the existence of long-standing industry-academic partnerships that have already established similar project support relationships. The inability to directly reach out to industry is also a significant challenge to this goal. While industry groups such as NDIA are a worthwhile approach these groups are primarily intended to connect and develop relationships between industry and government, not industry and academia. Encouraging and enabling independent individuals to serve as mentors and gain an appreciation for the CM may act to open a door to broader industry participation.

Increasing academic participation is clearly a need if the CM is to continue. Several lessons learned regarding opportunities and challenges to broader participation are noted in this report. A key finding in this regard may be that outreach to smaller schools where established industry & government relationships do not already exist would be worthwhile. Flexibility in timing, team make-up, and multi-school collaboration should be part of this outreach effort. Encouraging frequent use of the new CM website as a resource should increase awareness of the CM and lead to broader student participation and/or encouragement of faculty participation. Additional steps need to be implemented to ensure that any communication breakdowns between SMEs and student teams are resolved quickly and results verified. This could be done through the CM website using a shared calendar with noted milestones.

The primary sponsor of CM projects has expressed a clear desire for them to continue. They have provided excellent SME's and approached participation from an excellent perspective of steering students but not directing them towards a given solution. In several instances this approach has led to solutions that have been moved forward for additional research. The nature of the sponsors schedule and funding calendar relative to the academic calendar is a significant problem that must be resolved.